寄生蜂取食寄主特性及其在害虫生物防治中的作用

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摘要：许多寄生性天敌昆虫的雌虫不仅寄生寄主，而且还能取食寄主。在卵育型(synovigenic)寄生蜂类群中，取食寄主行为是较为普遍的现象。本文综合近20年相关研究进展，从寄生蜂类群、取食类型、生态学意义及影响因子等方面对寄生蜂的取食寄主行为进行了归纳总结。寄生蜂通过取食不仅可以杀死寄主，直接起到控制害虫种群数量的作用，还能通过取食策略为卵的成熟和再生提供营养来源，对延长雌虫的寿命也有一定的帮助。对取食寄主行为的了解可为筛选优势寄生性天敌种类、评估寄生蜂在害虫生物防治中的作用提供重要信息。

关键词：取食寄主行为；寄生；卵育型寄生蜂；天敌；生物防治
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Host-feeding behaviors of parasitoids on hosts and implications for biological control

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Abstract: Many species of insect parasitoids not only parasitize hosts but can also feed and kill them. As for synovigenic parasitoid wasps, host-feeding behavior has been regarded as a common habit in them. In this article, host-feeding behaviors in hymenopteran parasitoids were summarized in the view of involved parasitoid species, foraging type, ecological significance, and impact factors over the past two decades. Parasitoid wasps kill significant numbers of hosts by feeding, as well as by parasitism, which plays important roles in reducing population size of insect pests. Meanwhile, host-feeding benefits the parasitoids by supplying nutrients needed for egg maturation and reproduction. Sometimes host-feeding also prolongs the longevity of parasitoids. Understanding the host-feeding strategies can provide important information for screening dominant insect parasitoids and evaluating their effectiveness in biological control on insect pests.

Key words: Host-feeding behavior; parasitism; synovigenic parasitoid; natural enemy; biological control

寄生性天敌昆虫能将卵产于其他昆虫的体内或体外，并借助寄主的营养来完成其后代的发育，这些天敌的寄生生物学特性在控制害虫的种群数量中发挥了重要作用，因而也引起人们的广泛关注(Chan and Godfray, 1993)。许多寄生蜂的雌虫不仅能寄生寄主，而且还可通过取食寄主策略来杀死它们。所谓取食寄主(host-feeding)就是指寄生蜂雌成虫摄食寄主血淋巴和组织的行为。取食寄主现象主要报道于膜翅目寄生蜂中，不过也发现有少数双翅目寄生蝇有取食寄主行为(Nettles, 1987)。寄生蜂取食寄主行为较长时间以来一直未引起重视，但自从英国昆虫学家 Jervis 和 Kidd (1986)对寄生蜂的取食寄主行为的多样性进行综述以来，生物防治工作者逐渐认识到这种行为的重要性。

膜翅目寄生蜂依据羽化时体内卵的发育状况分为卵熟型(pro-ovigenic)寄生蜂和卵育型(synovigenic)寄生蜂(Flanders, 1950)。前者的雌虫在羽化时体内的卵已完全成熟或接近成熟，因而一般不需要再补充营养。相反，后者在羽化时卵还未成熟或仅有少量卵生成，尚需要雌虫能够取食利

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用寄主材料和(或)其他营养源(如蜜露、植物分泌物和露水等)。对于卵育型寄生蜂来说，取食寄主策略不仅为卵的成熟和再生提供了良好的营养来源，而且还能延长雌虫的寿命。

在寄生蜂类群中，取食寄主行为是较为普遍存在的现象，在害虫生物防治中具有实际生态学意义。本文在 Jervis 和 Kidd(1986)一文的基础上，归纳总结了近 20 年相关研究，从寄生蜂类群、取食类型、生态学意义及影响因子等方面对寄生蜂的取食寄主行为及其在害虫生物防治中的作用做一综述。

1 取食寄主行为类型

根据取食和寄生是否发生在同一寄主上，可将寄生蜂取食寄主行为分为同时发生型和非同时发生型。根据取食的后果即是否导致寄主死亡，可将寄生蜂取食寄主行为分为致死型和非致死型(Jervis and Kidd, 1986)。

1.1 同时发生型和非同时发生型

同时发生型(concurrent)指取食和产卵发生在同一寄主个体上，而非同时发生型(non-concurrent)为取食和产卵发生在不同寄主个体上。但需要指出的是，这两种类型并不相互排斥，例如有些寄生蜂种类雌虫的卵巢内没有成熟的卵，或面对的寄主个体并不适合产卵时，取食表现为非同时发生型，反之，表现为同时发生型。

1.2 致死型和非致死型

致死型(destructive)指寄生蜂取食后直接导致寄主死亡，而非致死型(non-destructive)指寄主在寄生蜂取食后仍然可以存活。非致死型取食可以是同时发生型，也可以是非同时发生型。死亡寄主一般不适合寄生蜂发育，因此，致死型取食通常属于非同时发生型。许多致死型取食者主要或专一地取食不适合产卵的寄主龄期(Kidd and Jervis, 1991a, 1991b)，有时在寄主利用上还表现出一些其他差异，例如有些寄生蜂不仅取食寄主，还取食非寄主种类(Cate *et al.*, 1977; Shaw, 1983)。不过在少数营外寄生的种类中，致死取食并不阻止寄生蜂的发育，例如 *Muscidifurax raptor* Girault & Saunders 仍然可以在人工刺死的寄主上发育(Klunker, 1982)。在 Jervis 和 Kidd 等人归纳的基础上(Jervis and Kidd, 1986; Kidd and Jervis, 1991a)，结合最近的相关研究报道，我们对具有取食寄主行为的寄生蜂种类进行了重新归纳总结(表 1)。总的来看，在已明确取食类型的寄生蜂种类中，非同时发生-致死型所占的比例最高(约为 65%)，其次为同时发生-非致死型(约占 17%)。

2 具有取食寄主特性的寄生蜂类群

取食寄主行为在卵育型寄生蜂中普遍存在。根据已有的文献资料，140 余种膜翅目寄生蜂被记录有取食寄主习性，其中的一些种类已成功用于害虫防治(Jervis and Kidd, 1986)。依据全世界寄生蜂种类的统计数据，Kidd 和 Jervis(1991a)预测具有取食寄主习性的寄生蜂可能有 100 000 种。虽然被记录有取食寄主行为的寄生蜂种类很多，但已明确取食寄主行为模式的还不是很多。由表 1 可知，目前已明确取食寄主类型最多种类的类群为蚜小蜂科，共计 18 种(取食的寄主阶段主要为若虫，取食类型几乎都为非同时发生－致死型)；其他类群按所含种类的多少降序排列，依次为姬蜂科(13 种)、姬小蜂科(10 种)、螯蜂科(7 种)、金小蜂科(6 种)、肿腿蜂科(3 种)和跳小蜂科(3 种)，赤眼蜂科、茧蜂科和旋小蜂科中也有少数种类的取食类型已明确。

3 取食寄主行为的生态学意义

3.1 降低害虫种群数量

许多报道都表明寄生蜂的取食寄主行为是控制害虫种群数量的重要因子，特别是一些致死取食型寄生蜂种类，表现出超强的取食寄主能力，其控制作用更加明显。例如在田间情况下，卵寄生蜂 *Tetrastichus asparagi* Crawford 通过取食可以杀死 71% 的寄主卵(Johnston, 1915)；*Metaphycus helvolus* (Compere)通过取食导致寄主 *Saissetia oleae* Bernard 的死亡率高达 55%(DeBach, 1943)；在室内 *Trichogramma turkestanica* Meyer 取食 *Ephestia kuehniella* Zeller 卵的数量与寄生的数量差不多(Hansen and Jensen, 2002)；最近 Zang 和 Liu (2008)也发现，在温室条件下，兼性超寄生蜂 *Encarsia sophia*(Girault & Dodd)因取食导致烟粉虱若虫的死亡率高达 59.7%，与寄生引起的寄主死亡数量相当。

3.2 增加繁殖

许多报道表明取食寄主和繁殖之间存在明显的正相关性，通过摄食寄主获取的营养不但可以促进卵的成熟还可以增加卵的生产(Flanders, 1935;

表1 目前已明确取食寄主行为的主要寄生蜂种类

Table 1 Parasitoid wasp species whose host-feeding type has been determined

寄生蜂 Parasitoid		寄主 Host		取食类型 Host-feeding type	参考文献 References
科 Family	种 Species	科 Family	种 Species		
蚜小蜂科	*Aphelinus asychis*	*Schizaphis graminum*	N	C-D/NC-D	Cate *et al*., 1977
Aphelinidae	*A. thomsoni*	*Drepanosiphum platanoidis*	N	NC-D	Collins *et al*., 1981
	A. flavus	*D. platanoides*	N	NC-D	Hamilton, 1973
	Aphytis melinus	*Aonidiella aurantii*	N-A	NC-D	Abdelrahman, 1974
	A. coheni DeBach	*A. aurantii*	N	NC-D	Avidov *et al*., 1970
	A. lingnanensis	*A. aurantii*	N	NC-D	Quednau, 1964
	A. lepidosaphes	*Lepidosaphes beckii*	N	NC-D	DeBach and Landi, 1961
	A. aonidiae	*Quadraspidiotus perniciosus*	N-A	NC-D	Gulmahamad and DeBach, 1978
	A. chrysomphali	*Aonidiella aurantii*	N	NC-D	DeBach and White, 1960
	Encarsia formosa	*Trialeurodes vaporariorum*	N	NC-D	van Lenteren *et al*., 1987
	E. pergandiella	*Bemisia tabaci*	N	NC-D	Videllet *et al*., 1997
	E. sophia	*B. tabaci*	N	NC-D	Zang and Liu, 2008
	Eretmocerus mundus	*B. tabaci*	N	NC	Foltyn and Gerling, 1985
	E. melanocutus	*B. tabaci*	N	NC-D	Zang and Liu, 2008
	E. debachi	*Parabemisia myricae*	N	NC-D	Sengonca *et al*., 1994
	E. eremicus	*Trialeurodes vaporariorum*	N	NC	Zilahi-Balogh *et al*., 2006
	Physcus seminotus	*Aulacaspis tegalensis*	N-A	C/NC	Williams, 1972
	P. subflavus	*A. tegalensis*	N-A	C/NC	Williams, 1972
姬蜂科	*Pimpla turionellae*	*Galleria mellonella*	P	C-ND/NC-D	Sandlan, 1979
Ichneumonidae	*Itoplectis maculator*	*Tortrix viridana*	P	C-ND/NC-D	Cole, 1967
	I. conquisitor	*Coleophora pruniella*	P	C-ND/NC-D	Leius, 1961a
	I. naranyae	*Galleria mellonella*	P	C-D/NC-D	Ueno, 1998
	Apechthis rufatus	*Tortrix viridana*	P	C-ND/NC-D	Cole, 1967
	A. quadridentatus	*T. viridana*	P	C-ND/NC-D	Cole, 1967
	Agrothereutes lanceolatus	*Galleria mellonella*	P	NC-D	Ueno, 1999
	Scambus buolianae	*Galleria mellonella*	L	D	Leius, 1967
	Phaogenes nigridens	*Ostrinia nubilalis*	P	C-ND	Smith, 1932
	Diplazon laetatorius	*Episyrphus balteatus*	E; L	D	Rotheray, 1981
	D. tibiatorus	*Sphaerophora scripta*	E; L	D	Rotheray, 1981
	Enizemum ornatum	*Metasyrphus luniger*	E; L	D	Rotheray, 1981
	Homotropus pictus	*Platycheirus scutatus*	E	NC-D	Rotheray, 1981
姬小蜂科	*Sympiesis marylandensis*	*Phyllonorycter crataegella*	L	C-D/NC-D	Van Driesche and Taub,1983
Eulophidae	*Tetrastichus asparagi*	*Crioceris asparagi*	E	NC-D	Johnston, 1915
	T. flavigaster	*Paurocephala calodendri*	N	NC-D	Moran *et al*., 1969
	T. incertus	*Hypera postica*	L	C-ND/NC-D	Dowell, 1978
	Chrysocharis pentheus	*Phytomyza ranunculi*	L	NC-D	Sugimoto and Ishii, 1979

续表 1 Table 1 continued

寄生蜂 Parasitoid		寄主 Host		取食类型 Host-feeding type	参考文献 References
科 Family	种 Species	科 Family	种 Species		
	C. laricinellae	*Coleophora laricella*	L	C-D-ND/NC	Quednau, 1967
	Cirrospilus dialus	*Phyllonorycter* spp.	L	NC-D	Askew and Shaw, 1979a, 1979b
	Euplectrus parvulus	*Eudocima* spp.	L	NC-D	Chatterjee, 1945
	E. laphygmae	*Spodoptera littoralis*	L	NC-D	Gerling and Limon, 1976
	E. puttleri	*Anticarsia gemmatalis*	L	NC-D	Puttler *et al.*, 1980
螯蜂科	*Pseudogonatopus flavifemur*	*Nilparvat lugens*	N	NC-D	Chua *et al.*, 1984
Dryinidae	*P. nudus*	*N. lugens*	N	NC-D	Chandra, 1980
	Dicondylus bicolor	*Delphacidae* spp.	N	NC-D	Waloff, 1974
	D. helleni	*Calligypona sordidula*, *C. excisa*	N	NC	Raatikainen, 1961
	Gonatopus sepsoides	*Cicadellidae* spp.	N	C-D/NC-D	Waloff, 1974
	Haplogoashnatopus atratus	*Laodelphax striatellus*	N	NC-D	Kitamura, 1982
	Richardsidryinus pyrillae	*Pyrilla perpusilla*	N	NC-D	Subba Rao, 1957
金小蜂科	*Muscidifurax raptor*	*Musca domestica*	P	NC-D	Legner and Gerling, 1967
Pteromalidae	*Nasonia vitripennis*	*M. domestica*	P	C-ND/NC-D	Rivero and West, 2005
	Spalangia cameroni	*M. domestica*		NC-D	Legner and Gerling, 1967
	Asaphes lucens	*Aphidius smithi*	L	C-ND	Keller and Sullivan, 1976
	Dibrachoides dynastes	*Hypera postica*	P	C	Smith, 1930
	Schizonotus sieboldi	*Plagiodera versicolora*	P	C/NC	Dowden, 1939
肿腿蜂科	*Goniozus columbianus*	*Paralobesia viteana*	L	D	Cushman and Gordh, 1976
Bethylidae	*G. gallicola*	*P. viteana*	L	C	Gordh, 1976
	Pristocera rufa	*Pantorhytes szentivanyi*		ND	Baker, 1976
跳小蜂科	*Epidinocarsis lopezi*	*Phenacoccus manihoti*	N	D	Neuenschwander and Madojemu, 1986
Encyrtidae	*Metaphycus helvolus*	*Saissetia oleae*	N	NC-D	Lampson *et al.*, 1996
	Microterys flavus	*Coccus hesperidum*	N	NC-D	Bartlett, 1964
赤眼蜂科 Trichogrammatidae	*Trichogramma turkestanica*	*Ephestia kuehniella*	E	D	Hansen and Jensen, 2002
茧蜂科 Braconidae	*Bracon hebetor* Say	*E. cautella*	L	C-ND/NC-D	Hagstrum and Smittle, 1978
旋小蜂科 Eupelmidae	*Eupelmus vuilletti*	*Callosobruchus maculatus*	L	NC	Giron *et al.*, 2004

表中"阶段"栏中的 E = 卵, L = 幼虫, N = 若虫, P = 蛹, A = 成虫。"取食类型"栏中的 C = 同时发生, NC = 非同时发生, D = 致死, ND = 非致死。In the column of "stage", E = egg, L = larva, N = nymph, P = pupa, A = adult. In the column of "host-feeding type", C = concurrent, NC = non-concurrent, D = destructive, ND = non-destructive.

Bartlett, 1964; Heimpel and Collier, 1996)。最明显的例子，先取食后产卵型的(anautogenous)寄生蜂种类在羽化时没有成熟的卵，产卵前必须先取食以促进卵的成熟(Jervis and Kidd, 1986; van Lenteren *et al.*, 1987)。在自然条件下，寄生蜂既可以利用寄主血淋巴作为食源，也可以利用非寄主食物，如

花蜜、花粉及蜜露等(Jervis *et al*., 1996; Burger *et al*., 2004)。但对于多数寄生蜂来说，寄主的血淋巴对繁殖相当重要，例如 *Scambus buolianae* 的雌虫在喂食了不含有寄主血淋巴的食物后不会产卵，而且产卵量还取决于血淋巴的供应量(Leius, 1961b)以及寄主种类(Leius, 1962)。同喂食粉虱分泌的蜜露相比，取食寄主血淋巴的 *Encarsia formosa* Gahan 繁殖量更大(Burger *et al*., 2005)。最近，利用放射性标记氨基酸跟踪法证实，取食寄主同卵营养物质合成存在直接联系(Rivero and Casas, 1999; Rivero *et al*., 2001)。Giron 等(2004)的研究结果进一步表明，取食寄主材料中的脂肪对繁殖量起着关键作用。

3.3 延长寿命

同对繁殖量的影响相比，取食寄主行为对寄生蜂寿命的影响受到相对较小的关注。取食寄主对寿命的影响常随寄生蜂种类的不同而变化。在某些种类中，如 *Eupelmus vuilletti*，寄主的血淋巴是雌蜂唯一可用的食源，因而，取食寄主对于维持正常生命代谢非常重要(Giron *et al*., 2002)。从已经被研究过的种类可以看出，取食寄主可以增加姬蜂总科(Ichneumonoidea)和青蜂总科(Chrysidoidea)寄生蜂的寿命，在小蜂总科(Chalcidoidea)中，取食寄主只能延长部分种类的寿命(Heimpel and Collier, 1996)，这也反映不同类群寄生蜂在营养代谢或从取食寄主获取能量的方式上存在差异(Collier, 1995a)。最近 Giron 等(2004)的研究结果表明取食寄主材料中的碳水化合物对寄生蜂的寿命起着重要作用。

取食寄主行为带来很多益处的同时，寄生蜂也要付出一定的代价。一方面，取食直接杀死寄主可以引起用于产卵的寄主数量下降；还可能由于取食并未杀死寄主，但导致用于产卵的寄主质量下降，这种情况在同时发生-非致死取食类型的寄生蜂中较为常见(Jervis and Kidd, 1986)。不过，在许多情况下，这种损失可通过寄生蜂能主动选择低质量的寄主用于取食而选择高质量的寄主用于产卵来减小(van Alphen, 1980; Kidd and Jervis, 1991b)。从另外一个角度看，寄生蜂虽然由于取食丧失目前产卵的机会，但也可为将来的繁殖奠定基础。

另外一个同取食寄主行为相关的潜在代价就是处理时间的增加。许多寄生蜂种类取食常比产卵花费更长的时间(Bartlett, 1964; Hamilton, 1973; van Lenteren *et al*., 1980; Walter, 1986; Heinz and Parrella, 1989; Rosen *et al*., 1992; Takasu and Hirose, 1993)。当寄生蜂的繁殖受搜索时间限制时，增加的取食时间可代表实质性的功能损失(Charnov and Skinner, 1988)。此外，取食寄主时，处理时间长也使得寄生蜂更容易遭受天敌攻击(Bartlett, 1961; Iwasa *et al*., 1984)。

4 影响取食寄主行为的因子

4.1 内在因子

4.1.1 载卵量：可以预测载卵量在影响取食寄主策略上起着关键作用。当载卵量低，或产卵受限制的可能性最大时，取食寄主行为就可能发生(Heimpel and Collier, 1996)。这种预测已经被许多研究支持，例如，*Metaphycus helvolus* 只有在载卵数低于 4 个时才取食寄主(Flanders, 1942)。其他一些研究也表明寄生蜂在寄生一定量的寄主后，常伴随着取食活动(Bartlett, 1964; Reeve, 1987; van Lenteren *et al*., 1987)，这可能就与产卵后体内载卵量减少有关。Collier 等(1994)解剖调查了取食和载卵量的关系，结果证实取食与低载卵量相关联。

4.1.2 营养状态：当体内营养贮藏低时，寄生蜂正处于一种饥饿状态，此时极有可能发生取食行为。当寄主缺乏或稀少时，多数具有取食寄主习性的寄生蜂饥饿到一定程度，可以通过吸收体内的卵获取营养来维持生命(Jervis and Kidd, 1986)。在营养贮藏变化的过程中，可以预测，寄生蜂在饥饿到还未吸收体内的卵时，其取食欲望和能力可能达到最大值。我们的研究结果证实，羽化后饥饿 6 h 的 *E. sophia* 雌虫取食寄主的数量明显高于未经过饥饿处理的寄生蜂(Zang and Liu，未发表资料)。

4.1.3 消化道内溶物：消化道内溶物也会影响到取食寄主行为。例如 *Aphytis aonidiae*(Mercet)在喂食水和(或)蜂蜜后再取食寄主的量要明显少于那些不喂食任何食物的寄生蜂(Gulmahamad and DeBach, 1978)。单纯的以寄主为食而不食其他食物可能会影响到取食寄主率，同时以单一类型的寄主为取食对象也可能会使寄生蜂产生厌食反应(Heimpel and Collier, 1996)。Rosenheim 和 Rosen(1992)发现 *Aphytis lingnanensis* Compere 在以单一的低龄寄主为食时，在未食饱前即停止取食。田间观察也发现 *A. aonidiae* 在取食一定量的寄主后，还能继续取食蜂蜜(Heimpel and Collier, 1996)。这些都暗示消化道内溶物会在一定程度上影响寄生蜂的

取食寄主行为。

4.1.4 年龄：在成虫的整个生命周期中，不同种类寄生蜂常随着年龄的变化表现出不同的取食寄主能力。一些寄生蜂种类如 *Chrysocharis laricinellae* 和 *C. pentheus*，每日取食寄主的量相对恒定，一般不会随着年龄的增长而出现取食寄主能力的波动变化（Quednau，1967；Sugimoto and Ishii，1979）；而有些种类寄生蜂如 *A. lingnanensis*，*Encarsia formosa*，*E. pergandiella*，*Pholetesor ornigis*，在生命前期，随着年龄的增长，取食寄主的量逐渐增加，但在生命后期，随着产卵量的减少，取食寄主的量也开始下降（Arakawa，1982；Ridgeway and Mahr，1990；Videllet *et al*.，1997）。

4.2 外在因子

4.2.1 寄主质量：寄主被选择用来产卵还是取食，在质量上的要求可能是不一样的。寄主的大小是衡量质量的最主要标准，寄主越大含有越多的资源，因而可以生产出更多或更大的寄生蜂后代（Heimpel and Collier，1996）。许多研究表明早期阶段寄主更可能被用来取食，而不是产卵（Kidd and Jervis，1991a）。而且，当相同阶段的寄主被用来产卵和取食时，寄生蜂常偏好取食其中的小寄主（Heinz and Parrella，1989；Rosenheim and Rosen，1992；Heimpel and Rosenheim，1995）。但也有研究结果表明，在同时提供不同龄期的寄主时，粉虱寄生蜂 *E. sophia*，*E. formosa*，*Eretmocerus melanoscutus*（Zang and Liu，2008）以及 *E. pergandiella*（Videllet *et al*.，1997）更偏好取食后期寄主。也有寄主大小与取食行为不存在相关性的报道，如双翅目蛹寄生蜂 *Muscidifurax raptor*（Antolin，1989）。另外一方面，不同寄主种类因质量上的差异也会影响寄生蜂的取食和产卵行为。一般来说，可用作取食的种类范围常宽于用作产卵的种类范围（Heimpel and Collier，1996）。

4.2.2 寄主密度：寄主密度对取食寄主行为的影响是多方面的，没有一致的规律。可利用的寄主处于高、中和低密度均可影响到寄生蜂的取食。寄主密度对取食寄主策略的影响实验研究，更多地是关注在各密度下用于产卵的寄主数量同取食寄主数量的比率。Jervis & Kidd 分析模拟模型（Jervis and Kidd，1986）和 Chan & Godfray 动态模型（Chan and Godfray，1993）预测在多数情况下，产卵对取食的比率是寄主密度的一个正态函数，许多室内研究结果都支持这一模型（Löhr *et al*.，1988；Bai and Mackauer，1990；Sahragard *et al*.，1991）。例如，随着寄主密度的增加，*Aphelinus asychis*（Walker）每天寄生寄主的数量稳步增加，而取食寄主的数量始终恒定（1 个寄主/天）（Bai and Mackauer，1990）。目前只有少数研究评估了田间寄主密度同取食寄主行为的关系，且观察结果与室内研究的并不完全一致。Reeve 和 Murdoch（1985）报道在田间 *Aphytis melinus* 对 2 龄寄主的寄生反向地依赖寄主密度，而取食寄主行为不依赖寄主密度；对 3 龄寄主，产卵对取食的比率则不依赖寄主密度。在寄生蜂攻击 *Phyllonorycter* spp. 的研究中，Askew 和 Shaw（1979a，1979b）发现在 *P*. spp. 发生的后期，寄主处于高密度期时，因寄生蜂取食导致的寄主死亡数量在总死亡量占据更大的份额。

4.2.3 环境因素：已有的少数研究表明温、湿度及光照也可影响到寄生蜂的取食寄主行为，而且这些环境因素对不同寄生蜂取食寄主行为的作用也不尽相同。刘建军和田毓起（1987）发现温、湿度和光照对 *E. formosa* 取食寄主数量存在显著影响，在 27℃时，取食寄主 75 头，而 15℃时仅取食 24 头；相对湿度为 90%，75%，45% 和 30% 时对应的取食寄主数量分别为 22，43，49 和 76 头，表现为湿度越低，取食寄主越多；在自然光照（3 000 ~ 20 000 lx，光照 6 h）时，取食寄主 75 头，在人工光照（7 000 lx，光照 16 h）时，取食寄主 50 头，在无光照时，取食寄主仅为 36 头。Hansen 和 Jensen（2002）报道了在 15 ~ 20℃ 时，*T. turkestanica* 取食 53 ~ 55 个 *E. kuehniella* 卵，随着温度的升高，取食寄主量明显减少，在 25℃ 时取食量为 43 个，在 30℃ 时仅为 17 个。

5 结语与展望

本文综述表明，取食寄主行为在寄生蜂类群中普遍存在，并且这种行为在害虫生物防治中具有非常实际的生态学意义。在评估寄生性天敌的控制作用时，除寄生率被看作重要指标，仍不能忽视取食寄主策略所发挥的作用，尤其是对于卵育型寄生蜂，取食寄主能力及其对增加寄生蜂繁殖和延长寿命的作用，都应视为天敌效能评判的重要标准。

自 Jervis 和 Kidd（1986）一文发表以来，寄生蜂的取食寄主行为已经被广泛关注。有关这方面的研究也取得了诸多进展，特别是在与取食寄主行为相关的一些分析模型的建立（Houston *et al*.，1992；

Chan and Godfray, 1993; Collier, 1995b）以及同该行为相关联的生理学研究（Rivero and Casas, 1999; Rivero *et al.*, 2001; Giron *et al.*, 2004）等方面进展较快。但总的来看，大多数关于寄生蜂取食寄主行为的研究还仅限于单一种类。我们建议，今后的研究方向应侧重在相同条件下，比较不同寄生蜂种类的取食寄主行为在控制害虫方面的作用以及这种行为对繁殖和寿命的影响，而且需要明确寄生蜂取食寄主后通过何种生理学途径获取营养和能量。

许多著名学者都认为取食寄主行为，特别是致死型取食寄主行为是寄生蜂的一个良好特性，不仅因为这种行为是寄生以外的额外寄主死亡来源，而且一些寄生蜂还能通过取食杀死比寄生更多的寄主（Flanders, 1953; Kidd and Jervis, 1989; Jervis *et al.*, 1996）。目前，我国对寄生蜂的取食寄主行为研究还未引起足够重视，我国寄生蜂资源相当丰富，估计高达3万多种，本文将对推进我国生物防治领域的相关研究起到积极作用。

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